Heat Propagation Improvement in YBCO-Coated Conductors for Superconducting Fault Current Limiters

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Introduction:

In order to engineer high-temperature superconducting cable applications, such as YBCO-based CCs for RSFCLs, the adequate protection from their quench damages represents one of the crucial parameters [1]. For that reason one must properly model and construct such devices using, for example, FEM numerical simulations and various deposition thin film techniques, respectively, as is given in this contribution. Its objective is to improve the thermal stability in RSFCL devices by homogenizing heat dissipation, as well as, to optimize their designs in order to guarantee their safe integration in medium-voltage grid configuration.

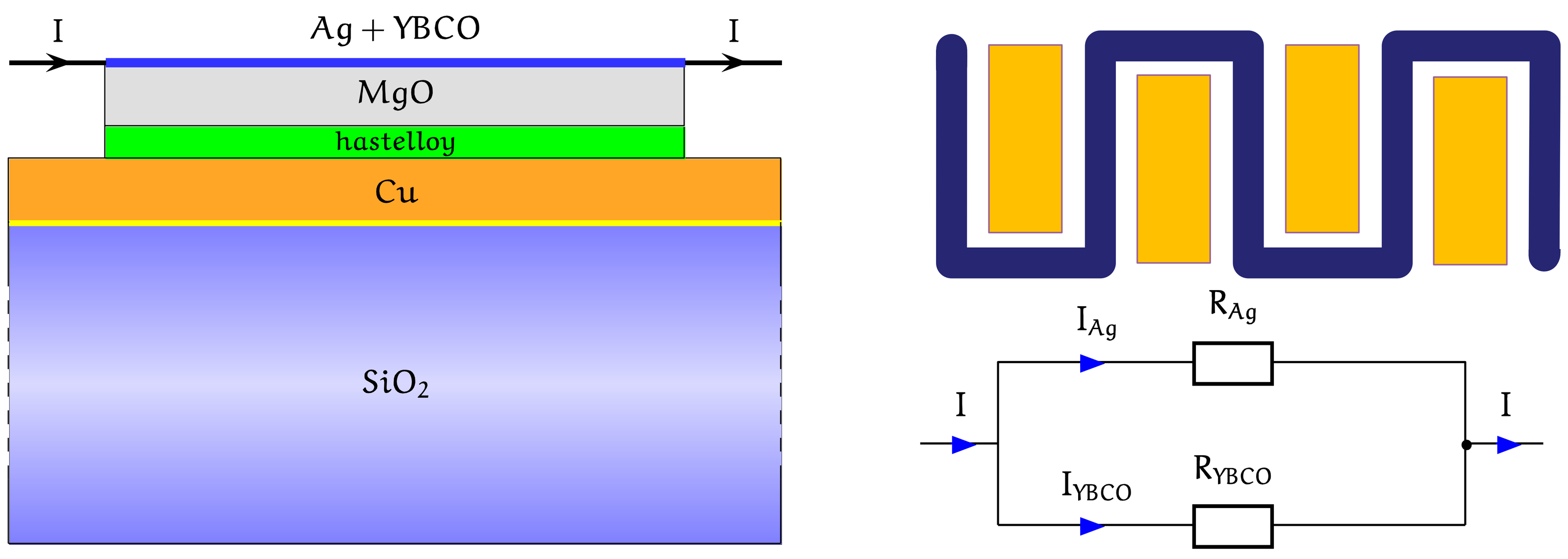

Figure 1. Novel multi-layered structure (left) used in a meander configuration (right ↑) of an YBCO-based CC for RSFCL. The current is shared in YBCO-based CC only (right ↓).

Computational Method:

The heat transfer time dependent simulations were carried out on a simple 3D meander geometry (Fig.1). The heat source was implemented as a T-J dependent power density function, evaluated numerically in R from the so-called current sharing function (see Figures 2 and 3 below). It assumes the following form of the YBCO resistivity:

$$\rho(J,T) = \rho_0 \cdot \left(\frac{J}{J_c(T)} - 1\right)^n, \text{with } J_c(T) = J_{c0} \cdot \left(1 - \frac{T}{T_c}\right)^{1/2} \cdot \left(1 - \left(\frac{T}{T_c}\right)^4\right)^{1/2}$$

Normal Zone Propagation Velocity (NZPV) was computed in COMSOL Multiphysics® directly as a first derivative of the expected value of spatial coordinate along the line (0<x<L), for which the Gaussian density distribution peak around T(x)=TNZ guarantees the highest probability. The line-width of the density function (δ) was controlled with the size of the projected mesh element (h) in order to ensure the smoothness of the generated <x(t)> function.

$$\upsilon_{NZP} = \frac{\delta}{\delta t} \frac{\int_{x=0}^{L} x \, e^{-\frac{(T(x)-T_{NZ})^2}{2\delta^2}} dx}{\left(\epsilon + \int_{x=0}^{L} e^{-\frac{(T(x)-T_{NZ})^2}{2\delta^2}} dx\right)}$$

$T_{NZ}=T_C \approx 92$ K, $h \times T'_x \ll \delta \ll T_{NZ}$, and convergence parameter ε.

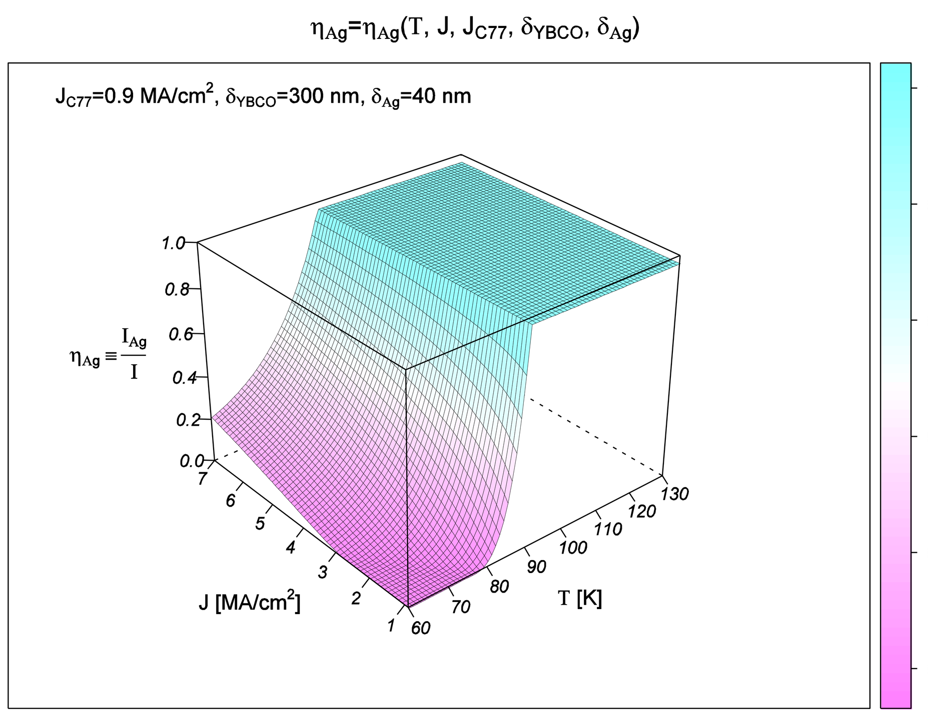

Figure 2. T-J dependent current sharing function.

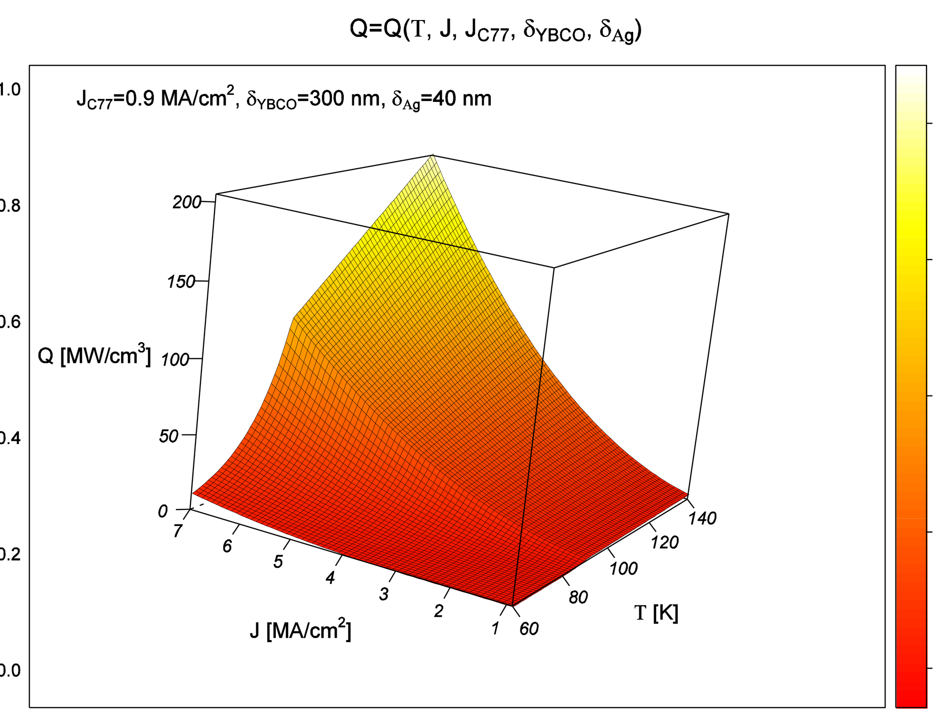

Figure 3. T-J dependent heat source function.

Results:

We present the computational results (Tab. 1) of the two NZPV components (Fig. 4) obtained for the following parameters: δ_{Ag}=40 nm, δ_{YBCO}=300 nm, δ_{MgO}= 2 μm, δ_{Hast}=1 μm, δ_{Cu}=1-5 μm, δ_{SiO2}=90 μm, J_C=2 MAcm^{-2}, J=2.5 MAcm^{-2}, and K_{inter}=300 WK^{-1}cm^{-2}. 3D geometry of three lines (each 6x20 mm^2), with the separation of 0.4 mm (Fig. 4), was meshed extrusively due to the multi-structured anisotropy. The mesh follows the condition delineated in Figure 5. The model was successfully validated with available experimental data for sapphire and hastelloy substrates.

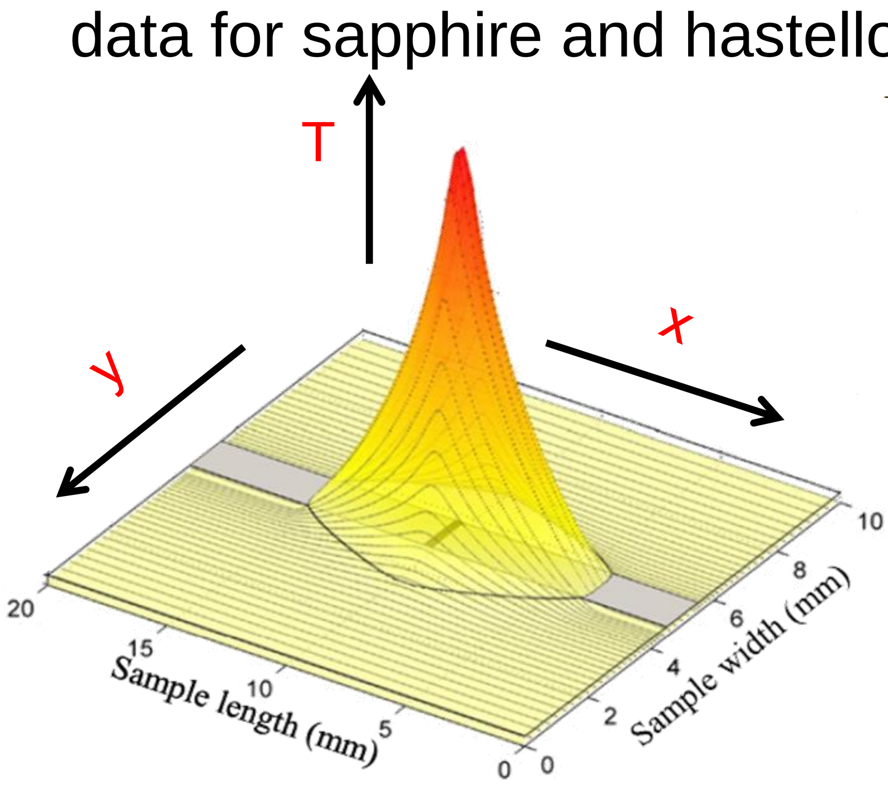

Figure 4. Longitudinal (x) and lateral (y) normal zone propagation across a line.

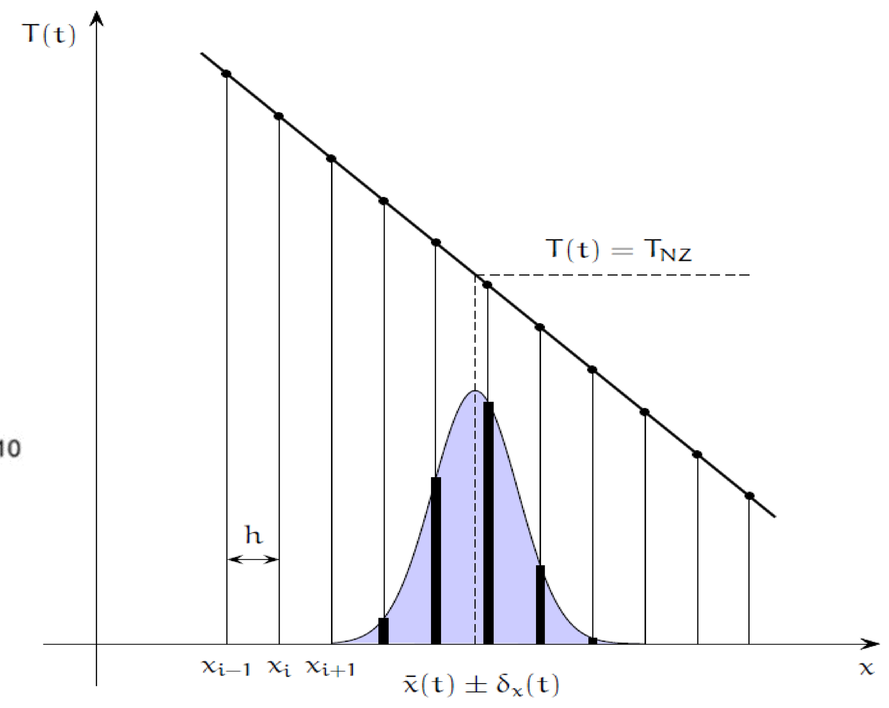

Figure 5. NZPV smoothness condition, h<<δ/T'$_x$, controlling the mesh size element.

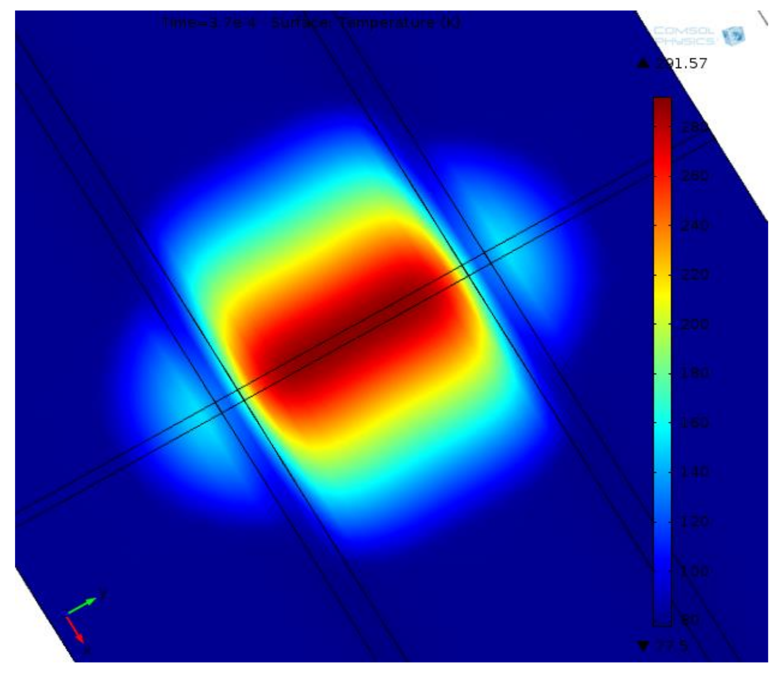

Figure 6. Temperature profile (δ_{Cu}=2 μm) measured at 340 μs after the transition (30 μs).

δ_{Cu} [μm]	υ_x [m/s]	υ_y [m/s]
1	4.50±0.05	4.0±0.1
2	4.60±0.05	4.0±0.2
3	4.65±0.05	4.0±0.2
4	4.70±0.05	4.1±0.3
5	4.70±0.05	4.1±0.3

Table 1. The longitudinal (υ_x) and lateral (υ_y) NZPVs values with respect to the Cu thickness (δ_{Cu}).

Conclusions:

In conclusion, the FEM model, which we have developed in COMSOL's Heat Transfer Module, has been found quite accurate to simulate the 3D transition-induced heat propagation in YBCO-based CCs used for RSFCLs with a simple meander geometry on a novel multi-structure (the ongoing experiment). We demonstrate that varying the Cu-substrate thickness (1-5 μm) has no considerable impact on both longitudinal and lateral NZPVs. However, their values have proven to fall into the almost two magnitude higher range as compared to the earlier studies [2], that is promising for commercialization purposes.

References:

1. Y. Wang, *Fundamental Elements of Applied Superconductivity in Electrical Engineering*, John Wiley & Sons, Singapore (2013).
2. A. Badel, L. Antognazza, M. Therasse, M. Abplanalp, C. Schacherer, and M. Decroux, *Hybrid Model of Quench Propagation in Coated Conductors for Fault Current Limiters*, Supercond. Sci. Technol. **25**, 095015 (2012).

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